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**English translation of the published  
application text  
(VERSION B)**

5 Filled, polymerizable dental material and process for  
the production thereof

10 The invention relates to a filled and polymerizable  
dental material, and to a process for the production  
thereof.

15 Various dental materials are used for prosthetic,  
preservative and preventive dentistry. These also  
include "composites", which contain one or more filling  
materials in a resin matrix. The fillers impart the  
desired mechanical properties to the dental materials;  
these include the rheology in the processing phase and  
mechanical properties such as hardness or abrasion  
resistance in the cured state. It has already been  
20 proposed (WO-A-020 92 022) to improve the mechanical  
properties of dental materials by addition of nanoscale  
fillers. The nanofillers disclosed in the specification  
mentioned are produced by a very complicated plasma  
torch process (PVS).

25 The present invention is based on the object of  
creating filled and polymerizable dental materials and  
also a process for the production thereof, where the  
dental materials can be produced inexpensively and have  
30 good mechanical properties such as, for example,  
compressive strength and abrasion resistance.

The invention achieves this object by means of a filled  
and polymerizable dental material which contains:

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a) an organic binder,

b) a nanoscale filler which has the following  
features:

- at least 50% by weight, preferably at least 60% by weight and particularly preferably at least 80% by weight of the nanoparticles have a particle diameter of less than 200 nm, preferably less than 150 or 100 nm,
  - at least 20 particle number%, preferably at least 30 particle number%, preferably at least 40 particle number% and particularly preferably at least 50 particle number%, of the nanoparticles are aggregated particles,
- c) at least one inorganic and/or organic filler selected from the group consisting of a ground filler having a mean particle size between 0.2  $\mu\text{m}$  and 50  $\mu\text{m}$  and a spherical filler having a mean particle size between 0.1  $\mu\text{m}$  and 50  $\mu\text{m}$ .

The process according to the invention for the production of such a dental material has the following steps:

- a) making available of:
- a1) an organic binder,
  - a2) an at least partially agglomerated and/or aggregated nanoscale filler,
  - a3) an agent for the organic surface modification of the organic filler a2),
  - a4) at least one inorganic and/or organic filler selected from the group consisting of a ground filler having a mean particle size between 0.2  $\mu\text{m}$  and 50  $\mu\text{m}$  and a spherical filler having a mean particle size between 0.1  $\mu\text{m}$  and 50  $\mu\text{m}$ ;

b) carrying out an organic surface modification of the filler a2) using the agent a3);

5 c) incorporation of the surface-modified nanoscale filler into the organic binder until at least 50%, preferably at least 60%, further preferably at least 80%, of the nanoscale filler has a particle diameter of less than  
10 200 nm, preferably less than 150 or 100 nm;

d) incorporation of the filler a4) into the organic binder;

15 where the steps c) and d) can be carried out in any desired sequence or simultaneously and where step b) is carried out before or simultaneously to the steps c) and/or d).

20 The core of the invention is combination of an inexpensively obtainable nanoscale filler defined in more detail in feature b) of claim 1 with a further (micro)filler defined in more detail in feature c) of claim 1. Nanoparticles can be prepared by the sol-gel  
25 process.

In this process, alkoxysilanes are hydrolyzed and the silanols formed are condensed relatively slowly to give nanoparticles. Essentially, only "primary particles"  
30 having a very uniform size distribution result. The process is very expensive, as the particles have to be prepared completely from silanes.

The flame-pyrolytic preparation of silicic acid is  
35 likewise known. Primary particles in the nano range can likewise result here. Under the reaction conditions of flame pyrolysis, however, to a large part "agglomerates" or "aggregates" result from the primary particles. The term aggregates designates particles in

which two or more primary particles are associated with one another by means of strong bonds such as, for example, sinter bridges. Agglomerates are particles in which two or more primary particles and/or aggregates  
5 are associated with one another by means of relatively weak bonds such as, for example, hydrogen bridges or dipole-dipole interactions. As a rule, in aggregates the primary particles are connected to one another superficially, in agglomerates as a rule rather point-  
10 like connections exist, i.e. the contact surfaces are comparatively small.

The aggregates and/or agglomerates formed from the primary particles are markedly larger than the primary  
15 particles, such that the flow behavior of an organic matrix containing such fillers is considerably influenced or worsened.

The invention has now recognized that, starting from  
20 fillers in which nanoscale primary particles are agglomerated and/or aggregated, it is nevertheless possible to arrive at a dental material having good mechanical properties. Preferably, these aggregated or agglomerated fillers are first organically surface-  
25 modified and subsequently incorporated into the organic binder, agglomerates and aggregates being destroyed by the incorporation to the extent that at least 50% by weight of the nanoparticles have a particle diameter of less than 100 nm (determined according to the process  
30 explained in more detail below). The invention thus allows the use of inexpensive starting materials for the nanoscale filler and nevertheless achieves that the dental materials according to the invention have the advantageous properties imparted by nanoscale fillers  
35 (in particular mechanical properties).

According to the invention, the nanoscale filler according to feature b) is still partly aggregated, i.e. a minimum amount of the nanoparticles defined in

more detail in the claim are aggregated particles in which two or more primary particles and/or agglomerates are connected by strong forces. In the case of very small primary particles, the aggregates can also still  
5 have a particle diameter of less than 100 nm; frequently, however, such aggregates exceed the indicated limit of the particle diameter of 100 nm.

The invention has thus recognized that a partial  
10 aggregation of the primary particles of the nanofiller does not or only insignificantly adversely affects the advantageous properties of a nanoscale filler and that the complicated preparation of nanofillers consisting only of primary particles (for example by the sol-gel  
15 process) can be dispensed with.

Fillers such as, for example, silicon dioxide obtained by flame pyrolysis have nanoscale primary particles which are held together in relatively large aggregates  
20 and/or agglomerates both by strong aggregate forces (in particular sinter bonds) and weak agglomerate forces. The process according to the invention is based on the realization that by mechanical incorporation of such fillers into an organic binder the agglomerate bonds  
25 are largely broken and the aggregate bonds are partly broken, such that after the incorporation the filler has the parameters defined in feature b) of the claim. The organic surface modification according to feature b) of claim 16 causes fresh agglomeration of primary  
30 particles or aggregates/agglomerates after the incorporation into the organic binder to cease. This organic surface modification can in particular be a silanization explained in more detail below. Preferably, the organic surface modification introduces  
35 groups onto the surface of the nanoscale fillers which can react chemically with the organic binder or have a high affinity for this organic binder.

The dental material according to the invention contains at least one further filler according to feature c) of claim 1. This can be a ground filler or a spherical filler (for example a spherical filler as  
5 described in DE-C 32 47 800) in each case having particle sizes defined in more detail. Both spherical and ground fillers have characteristic particle shapes, which differ markedly from the partly aggregated nanoparticles according to feature b). Nanoscale primary  
10 particles can have a similar particle shape to spherical fillers according to feature c), but differ markedly in particle size.

The invention makes available a dental material which,  
15 in spite of inexpensive production, has good mechanical properties.

Advantageous embodiments of the invention are indicated in the subclaims. Claims 2 to 4 mention preferred  
20 proportions by weight of the organic binder, nanoscale filler or of the additional filler according to feature c) of claim 1.

The mean primary particle size of the nanoscale filler according to the invention is between 1 nm and 80 nm,  
25 preferably between 4 nm and 60 nm and particularly preferably between 6 nm and 50 nm. The nanoscale filler according to the invention has a BET surface area (according to DIN 66131 or DIN ISO 9277) between 15 m<sup>2</sup>/g  
30 and 600 m<sup>2</sup>/g, preferably between 30 m<sup>2</sup>/g and 500 m<sup>2</sup>/g and particularly preferably between 50 m<sup>2</sup>/g and 400 m<sup>2</sup>/g.

The nanoscale fillers employed according to the  
35 invention are preferably metal, semimetal or mixed metal oxides, silicates, nitrides, sulfates, titanates, zirconates, stannates, tungstates or a mixture of these compounds. The group consisting of the semimetals, whose properties (especially appearance and electrical

conductivity) lie between those of the metals and the nonmetals, includes boron, silicon, germanium, arsenic, antimony, bismuth, selenium, tellurium and polonium (cf. Römpp Chemie Lexikon [Römpp's Chemical Encyclopaedia], Georg Thieme Verlag, 1990, p. 1711). The group consisting of the metals can be found in the periodic table left of the group consisting of the semimetals, i.e. includes the main group metals, subgroup metals, lanthanides and actinides. And the term mixed metal oxide, nitride, etc. is to be understood here as meaning a chemical compound in which at least two metals and/or semimetals together with the corresponding nonmetal anion (oxide, nitride, etc.) are combined with one another chemically.

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The nanoscale fillers employed according to the invention are particularly preferably silicon dioxide, aluminum oxide, zirconium dioxide, titanium dioxide, zinc oxide, tin dioxide, cerium oxide, aluminum-silicon oxides, silicon-zinc oxides, silicon-zirconium oxides, iron oxides and their mixtures with silicon dioxide, indium oxides and their mixtures with silicon dioxide and/or tin dioxide, boron nitride, strontium sulfate, barium sulfate, strontium titanate, barium titanate, sodium zirconate, potassium zirconate, magnesium zirconate, calcium zirconate, strontium zirconate, barium zirconate, sodium tungstate, potassium tungstate, magnesium tungstate, calcium tungstate, strontium tungstate and/or barium tungstate.

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In the process according to the invention, these nanoscale fillers are obtained by dispersing commercially obtainable, aggregated/agglomerated nanofillers (such as, for example, pyrogenic silicic acids) in an organic solvent and organically modifying them on the surface. During this organic modification, functional groups are applied to the surface of the nanoparticles which, on the one hand, are either covalently bonded or adsorptively bound to the



nanoparticles and which, on the other hand, can react chemically with the organic binder or have a high affinity for the organic binder. In the further steps, the dispersion of the modified nanofillers in the solvent is used directly or preferably the solvent is stripped off and then the dry nanopowder is incorporated into the organic binder. The organic surface modification can also be carried out directly in the organic binder.

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By means of this procedure, surprisingly the agglomerates and in some cases aggregates are permanently comminuted to the extent that at least 50%, preferably at least 60% and particularly preferably at least 80%, of the nanoparticles have a particle diameter of less than 100 nm. However, complete deaggregation is not achieved, i.e. at least 20%, preferably at least 30%, preferably at least 40% and particularly preferably at least 50%, of the nanoparticles are aggregated particles.

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The organic modification of the surface of the aggregated/agglomerated nanofillers is preferably carried out by treating with a siloxane, chlorosilane, silazane, titanate, zirconate, tungstate or with an organic acid (such as are described, for example, in US 6,387,981), an organic acid chloride or anhydride. The siloxanes, chlorosilanes, silazanes, titanates, zirconates and tungstates particularly preferably have the general formulae  $\text{Si}(\text{OR}')_n\text{R}_{4-n}$ ,  $\text{SiCl}_n\text{R}_{4-n}$ ,  $(\text{R}_m\text{R}''_{3-m}\text{Si})_2\text{NH}$ ,  $\text{Ti}(\text{OR}')_n\text{R}_{4-n}$ ,  $\text{Zr}(\text{OR}')_n\text{R}_{4-n}$  and  $\text{W}(\text{OR}')_n\text{R}_{6-n}$ , where m and n is 1, 2 or 3; preferably, n is = 3. The group R' bonded via the oxygen is, just as in the case of R'', any desired organic functional group, preferably an alkyl group and particularly preferably a methyl, ethyl, propyl or isopropyl group. The functional group R is any desired organic group and is directly bonded to the silicon, titanium, zirconium or tungsten via a carbon atom. If m or n is 1 or 2, the

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groups R can be identical or different. R is preferably selected such that it has one or more functional groups which can react chemically with the organic binder or have a high affinity for the organic binder. These functional groups are also contained in the abovementioned organic acids, acid chlorides and anhydrides which can likewise be employed for organic surface modification. They are preferably acrylate, methacrylate, cyanoacrylate, acrylamide, methacrylamide, vinyl, allyl, epoxide, oxetane, vinyl ether, amino, acid, acid ester, acid chloride, phosphate, phosphonate, phosphite, thiol, alcohol and/or isocyanate groups. The byproducts formed in the organic surface modification of the nanofillers, such as, for example, alcohols, hydrochloric acid or ammonia, are removed in the subsequent steps except for possible residues (impurities), i.e. they are no longer contained or only contained in small amounts of  $\leq 0.1\%$  by weight, preferably  $\leq 0.05\%$  by weight, in the dental material produced later.

A further advantageous option of the invention is the organic modification of the surface of the nanofillers with dyes. In this case, the group R of the compound used for the surface modification comprises a dye or a functional group which can react with a dye. The bonding of the dye to the surface of the nanofillers can take place both by means of a covalent bond and by means of an ionic bond.

The solvent in which the organic surface modification of the nanofillers is carried out is preferably a polar aprotic solvent and particularly preferably acetone, butanone, ethyl acetate, methyl isobutyl ketone, tetrahydrofuran or diisopropyl ether. Furthermore, the direct organic surface modification of the nanofillers in the organic binder to be used for the production of the dental materials is a particularly preferred procedure. In this case, the organic binder is the

solvent to be used. For the acceleration of the organic surface modification of the nanofillers, an acid can be added as a catalyst. In any case, catalytic amounts of water, preferably between 0.01% and 5%, must  
5 be present in order to carry out the modification. This water is often already present as an adsorbate on the surfaces of the aggregated/agglomerated nanofillers used as a starting substance. For assisting the reaction, further water, e.g. also in the form of a  
10 dilute acid, can be added.

In order to accelerate the disintegration of the agglomerates and aggregates in the organic solvent during the organic surface modification, before and  
15 during the modification an additional energy input can be carried out using the customary methods. This can be carried out, for example, by means of a high-speed stirrer, a dissolver, a bead mill or a mixer. In the case of the use of relatively highly viscous solvents,  
20 this is the preferred procedure, i.e. particularly if the organic binder is used directly as a solvent. If the organic binder is not used as a solvent, the organic binder to be used can be filled directly into the organic solvent with the dispersion of the  
25 organically modified nanofiller. In this case, the solvent is stripped off after the preparation of the mixture of organic binder and organically modified nanofiller or only during the later use of the nanofilled dental material. The latter is particularly  
30 a practicable procedure in the case of solvent-containing lacquers based on the dental materials according to the invention. Preferably, the organically modified nanofiller is freed of the solvent and processed further as a dry powder. In this case, the  
35 dry organically modified nanopowder is then added to the organic binder and incorporated with mechanical energy input. The incorporation can be carried out, for example, by means of a high-speed stirrer, a dissolver, a bead mill, a roll mill, a kneader or a mixer.

In the case of the use of relatively highly viscous solvents and in particular in the case of the direct use of the organic binder as a solvent, it can happen  
5 that possible excesses and/or unreacted parts of the compound used for the organic surface modification of the nanofillers cannot be removed from the dispersion. In this case, the preferred procedure is that these possible excesses and/or unreacted parts of the  
10 compound used for the organic surface modification of the nanofillers are converted by reaction with a suitable agent into substances which are then either removed from the dispersion or else can remain in the dispersion if they are inoffensive, i.e. not harmful,  
15 to humans. A particularly preferred procedure is the use of water as an agent which is reacted with possible excesses and/or unreacted parts of the compound used for the organic surface modification of the nanofillers.

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The organic binder employed is a compound or a mixture of a number of compounds which contains free radical-polymerizable and/or cationically and/or anionically  
polymerizable groups and/or groups which allow curing  
25 by means of a condensation and/or addition reaction and/or by means of an acid-base reaction. The compounds consist of a phosphazene-based, silicon-based or organic (carbon-based) parent structure and at least one functional group, which is bonded to this parent  
30 structure and which allows curing which proceeds by means of a free radical and/or cationic and/or anionic polymerization reaction and/or by means of a condensation and/or addition reaction and/or by means of an acid-base reaction. These functional groups are  
35 preferably acrylate, methacrylate, cyanoacrylate, acrylamide, methacrylamide, vinyl, allyl, epoxide, oxetane, vinyl ether, amino, acid, acid ester, acid chloride, phosphate, phosphonate, phosphite, thiol, alcohol and/or isocyanate groups. The acid, acid ester

and acid chloride groups can be derived, for example, from carboxylic acids, phosphoric acids, phosphonic acids or sulfonic acids.

- 5 The parent structure can be of linear, branched, cyclic, dendritic and/or hyperbranched construction. The parent structure can be a monomeric, oligomeric or polymeric structure. The chemical structure of the parent structure is constructed from aliphatic, cyclo-
- 10 aliphatic, heterocyclic, aromatic and/or heteroaromatic segments. One or more functional groups can be contained within the aliphatic, cycloaliphatic, heterocyclic, aromatic and/or heteroaromatic segments, e.g.
- 15 -O-, -S-, -SO-, -SO<sub>2</sub>-, -NR<sup>1</sup>-, -PR<sup>1</sup>-, -P(OR<sup>1</sup>)-, -POR<sup>1</sup>-, -PO(OR<sup>1</sup>)-, -O-PO(OR<sup>1</sup>)-O-, -CO-, -CO<sub>2</sub>-, O-CO-O-, -COS-, -CS<sub>2</sub>-, -C=N-, -N=C=N-, -CO(NR<sup>1</sup>)-, O-CO-NR<sup>1</sup>-, -NR<sup>1</sup>-CO-NR<sup>2</sup>-, -SiR<sup>1</sup>R<sup>2</sup>- and/or -SiR<sup>1</sup>R<sup>2</sup>-O-, where R<sup>1</sup> =H or any desired organic radical, preferably an
- 20 unsubstituted or substituted alkyl or aryl radical
- R<sup>2</sup> =H or any desired organic radical, preferably an unsubstituted or substituted
- alkyl or aryl radical; identical to or different
- 25 from R<sup>1</sup>.

If aliphatic segments are contained in the parent structure, these are preferably derived from substituted (e.g. halogenated) and unsubstituted alkyl

30 and alkenyl compounds, ethers, esters, carbonates, urethanes, polyethers, polyesters, polycarbonates and polyurethanes.

If cycloaliphatic segments are contained in the parent

35 structure, these are preferably derived from substituted (e.g. halogenated) and unsubstituted cycloalkanes (such as, for example, cyclohexane and its derivatives), spirans (such as, for example, spiro-[3.3]heptane) and bi- and polycyclic hydrocarbons (such

as, for example, decalin, norbornane, norcarane, pinane, adamantane, twistane and diamantane).

5 If heterocyclic segments are contained in the parent structure, these are preferably derived from substituted (e.g. halogenated) and unsubstituted cyclodextrins, morpholines and iminooxadiazinediones.

10 If aromatic segments are contained in the parent structure, these are preferably derived from substituted (e.g. halogenated) and unsubstituted benzenes (such as, for example, benzene, toluene, phenol, aniline and biphenyl) and fused aromatic ring systems (such as, for example, indene, fluorene, 15 naphthalene, acenaphthene, anthracene, phenanthrene, naphthacene, pyrene and chrysene).

If heteroaromatic segments are contained in the parent structure, these are preferably derived from 20 substituted (e.g. halogenated) and unsubstituted pyrroles, furans, thiophenes, indoles, benzofurans, benzothiophenes, dibenzofurans, dibenzothiophenes, pyrazoles, imidazoles, pyridines, pyrans, thiopyrans and quinolines.

25 As an organic binder, a liquid crystalline compound or a mixture of a number of compounds, of which at least one is liquid crystalline, can also be employed which contains free radical-polymerizable and/or cationically 30 and/or anionically polymerizable groups and/or groups which allow curing by means of a condensation and/or addition reaction and/or by means of an acid-base reaction.

A further preferred option is the use of a fluoride 35 ion-releasing compound or a mixture of a number of compounds, of which at least one can release fluoride ions, as an organic binder which additionally contains free radical-polymerizable and/or cationically and/or anionically polymerizable groups and/or groups which

allow curing by means of a condensation and/or addition reaction and/or by means of an acid-base reaction.

- 5 As organic binders, acrylates, methacrylates, acrylamides, methacrylamides, vinyl ethers, epoxides, oxetanes, spiroorthocarbonates, spiroorthoesters, bicyclic orthoesters, bicyclic monolactones, bicyclic bislactones, cyclic carbonates, cyclic acetals, allyl
- 10 sulfides, vinylcyclopropanes, organic phosphates, organic phosphonates, organic phosphites or a combination of these compounds are particularly preferably employed. Not restricting generality, some examples are mentioned below:
- 15 methyl (meth)acrylate, ethyl (meth)acrylate, n- or i-propyl (meth)acrylate, n-, i- or tert-butyl (meth)acrylate, hexyl (meth)acrylate, 2-ethylhexyl (meth)acrylate, cyclohexyl (meth)acrylate, isobornyl (meth)acrylate, hydroxyethyl (meth)acrylate, hydroxypropyl
- 20 (meth)acrylate, phosphoric acid esters of hydroxyethyl (meth)acrylate or hydroxypropyl (meth)acrylate, (meth)acrylic acid, malonic acid mono(meth)acrylate ester, succinic acid mono(meth)acrylate ester, maleic acid mono(meth)acrylate ester, glyceryl (meth)acrylate,
- 25 glyceryl (meth)acrylate ester, glyceryl di(meth)acrylate, glyceryl di(meth)acrylate ester (such as, for example, glyceryl di(meth)acrylate succinate), 4-(meth)acryloyloxyethyltrimellitic acid, bis-4,6- or bis-2,5-(meth)acryloyloxyethyltrimellitic acid, 2-
- 30 (((alkylamino)carbonyl)oxy)ethyl (meth)acrylate, allyl (meth)acrylate, butanediol di(meth)acrylate, hexanediol di(meth)acrylate, decanediol di(meth)acrylate, dodecanediol di(meth)acrylate, ethylene glycol di(meth)acrylate, diethylene glycol di(meth)acrylate,
- 35 triethylene glycol di(meth)acrylate, tetraethylene glycol di(meth)acrylate, polyethylene glycol di(meth)acrylates, glyceryl di(meth)acrylate, glycerol propoxytri(meth)acrylate, trimethylolpropane tri(meth)acrylate, ethoxylated and/or propoxylated

trimethylolpropane tri(meth)acrylates,  
 pentaerythritol tetra(meth)acrylate, dipentaerythritol  
 hexa(meth)-acrylate, bisphenol A di(meth)acrylate,  
 ethoxylated and/or propoxylated bisphenol A  
 5 di(meth)acrylates, 2,2-bis-4-(3-(meth)acryloxy-2-  
 hydroxypropoxy)phenylpropane and compounds derived  
 therefrom, chloro- and bromo-phosphoric acid esters of  
 bisphenol A glycidyl (meth)acrylate, urethane  
 (meth)acrylates (such as, for example, 7,7,9-  
 10 trimethylol-4,13-dioxo-3,14-dioxa-5,12-diaza-hexadecane  
 1,16-dioxydimethacrylate), polyester-urethane  
 (meth)acrylates, polyester (meth)acrylates,  
 polycarbonate (meth)acrylates, polyamide (meth)-  
 acrylates, polyimide (meth)acrylates, phosphazene  
 15 (meth)acrylates and siloxane (meth)acrylates; ethyl  
 vinyl ether, n- or i-propyl vinyl ether, n-, i- or  
 tert-butyl vinyl ether, hexyl vinyl ether, octyl vinyl  
 ether, cyclohexyl vinyl ether, cyclohexyl 3,4-epoxy-1-  
 methylvinyl ether, dimethanol cyclohexyl monovinyl  
 20 ether, 1,4-dimethanolcyclohexyl divinyl ether,  
 propanediol divinyl ether, butanediol divinyl ether,  
 hexanediol divinyl ether, octanediol divinyl ether,  
 decanediol vinyl ether, ethylene glycol divinyl ether,  
 diethylene glycol divinyl ether, triethylene glycol  
 25 divinyl ether, triethylene glycol monovinyl ether  
 mono(meth)acrylic acid ester, polyethylene glycol  
 divinyl ether, tripropylene glycol divinyl ether,  
 glyceryl trivinyl ether, pentaerythritol tetravinyl  
 ether, 7,7,9-trimethyl-4,13-dioxo-3,14-dioxa-5,12-  
 30 diaza-hexadecane-1,16-dioxydivinyl ether, bisphenol A  
 divinyl ether, ethoxylated and/or propoxylated  
 bisphenol A divinyl ether, polyester vinyl ethers,  
 polycarbonate vinyl ethers, polyacrylate vinyl ethers,  
 polyamide vinyl ethers, polyimide vinyl ethers,  
 35 polyurethane vinyl ethers, phosphazene vinyl ethers and  
 siloxane vinyl ethers; alkyl glycidyl ethers, glycidol,  
 glycidyl (meth)acrylate, dipentene dioxide, 1,2-epoxy-  
 hexadecane, bis(3,4-epoxycyclohexyl) adipate, vinyl-  
 cyclohexene oxides, vinylcyclohexene dioxides, epoxy-



cyclohexane carboxylates (such as, for example, 3,4-epoxycyclohexylmethyl 3,4-epoxycyclohexenecarboxylate), butanediol diglycidyl ether, hexanediol diglycidyl ether, dodecanediol diglycidyl ether, diglycidyl ethers of the polyethylene glycols and of the polypropylene glycols, diglycidyl ethers of substituted (e.g. halogenated) and unsubstituted bisphenols (such as, for example, bisphenol-A, bisphenol-C and bisphenol-F), resorcinol diglycidyl ether, trimetylolethane tri-glycidyl ether, trimethylolpropane triglycidyl ether, polybutadiene polyepoxides, polyester epoxides, polycarbonate epoxides, polyacrylate epoxides, polyamide epoxides, polyimide epoxides, polyurethane epoxides, phosphazene epoxides and siloxane epoxides; 3,3-disubstituted oxetanes and dioxetanes (such as, for example, 3-ethyl-3-(2-hydroxyethyl)oxetane); (trans/trans)-2,3,8,9-di-(tetramethylene)-1,5,7,11-tetraoxaspira[5.5]undecane; substituted 1,3-dioxolanes (such as, for example, 2-phenyl-4-methylene-1,3-dioxolane); difunctional 6-methylene-1,4-dithiepanes, and the reaction products of nucleophilic (meth)acrylates such as, for example, 2-hydroxyethyl (meth)acrylate or glyceryl (meth)acrylate esters with reactive phosphoric acid, phosphonic acid or phosphinic acid derivatives such as, for example,  $P_2O_5$ ,  $POCl_3$  or  $PCl_3$ .

The mixtures of organic binder and organically modified nanofiller obtained are distinguished by a high transparency and a low viscosity. In the case of use as a dental material, however, they are not suitable for all applications, since they have a high polymerization shrinkage and a relatively low mechanical strength. Therefore, according to the invention at least one inorganic and/or organic filler selected from the group consisting of ground fillers having a mean particle size between 0.2  $\mu m$  and 50  $\mu m$  and spherical fillers having a mean particle size between 0.1  $\mu m$  and 50  $\mu m$  is homogeneously incorporated into the mixtures described

above. A material is thereby obtained that is distinguished by a higher compressive strength, a lower polymerization shrinkage and an improved abrasion resistance.

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These dental materials according to the invention can have very different consistencies; they can be, for example, flowable and also rigid, i.e. modelable. Moreover, they can have very different rheological properties; they can be, for example, thixotropic, shear thickening or shear thinning. A high translucency, i.e. a low opacity in the dental materials according to the invention is likewise possible.

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The inorganic and/or organic filler described above is incorporated into the mixture of organic binder and organically modified nanofiller with mechanical energy input. The incorporation can be carried out, for example, by means of a high-speed stirrer, a dissolver, a bead mill, a roll mill, a kneader or a mixer.

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In the process according to the invention, the surface modification of the nanoscale filler is carried out either before or simultaneously to the incorporation into the organic binder. The further (spherical and/or ground) filler can be incorporated into the organic binder before, simultaneously to or after the nanoscale filler.

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The inorganic and/or organic filler can be a non-reactive filler, a reactive filler or a mixture of these two types of filler. A reactive filler is understood here as meaning a filler which with ingress of water releases ions and can thus lead to a curing of the material by means of an acid-base reaction. These reactive fillers are used, for example, for the preparation of compomers and glass ionomer cements and

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are described, for example, in D. C. Smith, Biomaterials 19, pp. 467-478 (1998).

As an inorganic and/or organic filler, preferably  
5 quartz powder, glass powder, glass ceramic powder, metal oxides, metal hydroxides, filled and/or unfilled chip polymers, filled and/or unfilled bead polymers, spherical fillers as described, for example, in DE-C 3247800 or a mixture of these fillers are employed. The  
10 chip and bead polymers are homo- or copolymers of the polymerizable compounds (usable as an organic binder) already described, it being possible to fill these homo- or copolymers with the nanofillers and/or inorganic fillers described such as, for example,  
15 quartz powder, glass powder, glass ceramic powder, pyrogenic or wet-precipitated silicic acids. Chip polymers are obtained by grinding the corresponding polymerization products.

20 As an inorganic and/or organic filler, barium silicate glasses, strontium silicate glasses, borate aluminosilicate glasses, phosphate aluminosilicate glasses, fluoroaluminosilicate glasses, calcium  
silicates, zirconium silicates, sodium aluminum  
25 silicates, layer silicates, bentonites, zeolites including molecular sieve, the oxides and the hydroxides of the alkali metals and the alkaline earth metals, apatite, filled chip polymers, spherical fillers as described, for example, in DE-C 3247800 or a  
30 mixture of these fillers are particularly preferably employed.

A preferred variant is the use of an inorganic and/or organic filler, in which by means of organic  
35 modification functional groups are applied to the surface of the filler which can react chemically with the organic binder or have a high affinity for the organic binder. These functional groups are preferably acrylate, methacrylate, cyanoacrylate, acrylamide,

methacrylamide, vinyl, allyl, epoxide, oxetane, vinyl ether, amino, acid, acid ester, acid chloride, phosphate, phosphonate, phosphite, thiol, alcohol and/or isocyanate groups. Preferably, these groups are introduced by means of the compounds already described in the surface modification of the nanofillers (siloxanes, chlorosilanes, silazanes, titanates, zirconates, tungstates, organic acids, organic acid chlorides or anhydrides).

10

A particularly preferred variant is the use of an inorganic and/or organic filler which is X-ray opaque and is incorporated into the dental material according to the invention in such amounts that the dental material according to the invention has an X-ray opacity (according to ISO 4049-2000) of preferably  $\geq 100\%$  Al and particularly preferably  $\geq 200\%$  Al.

For the adjustment of the viscosity of the dental material according to the invention, pyrogenic or wet-precipitated silicic acid can optionally additionally be incorporated into the dental material according to the invention:

The dental material according to the invention can be both a single-component material and a multicomponent material, where in the latter case at least one of the components, preferably all components, correspond to the composition according to the invention. The invention thus also relates to a kit for the production of a dental material according to the invention; the kit can contain one or more components. In the multicomponent kit or system, the production of a dental material according to the invention is carried out by mixing the components in the specified mixing ratio and subsequent curing.

For the curing of the dental material according to the invention an initiator or a number of initiators and

optionally a coinitiator or a number of coinitiators is preferably incorporated into the dental material according to the invention. Here, initiator or initiators and coinitiator or coinitiators can be  
 5 contained together in one component and/or separately in two or more components. The dental material according to the invention can thus be cured thermally, chemically, photochemically, i.e. by irradiation with UV and/or visible light, and/or by reaction with the  
 10 oral and/or atmospheric moisture.

The initiators usable here can be, for example, photo-initiators. These are characterized in that they can bring about the curing of the material by absorption of  
 15 light in the wavelength range from 300 nm to 700 nm, preferably from 350 nm to 600 nm and particularly preferably from 380 nm to 500 nm, and optionally by additional reaction with one or more coinitiators. Preferably, phosphine oxides, benzoin ethers, benzil  
 20 ketals, acetophenones, benzophenones, thioxanthenes, bisimidazoles, metallocenes, fluorones,  $\alpha$ -dicarbonyl compounds, aryldiazonium salts, arylsulfonium salts, aryliodonium salts, ferrocenium salts, phenylphosphonium salts or a mixture of these compounds  
 25 are employed here.

Particularly preferably, diphenyl-2,4,6-trimethylbenzoylphosphine oxide, benzoin, benzoin alkyl ethers, benzil dialkyl ketals,  $\alpha$ -hydroxyacetophenone, dialkoxy-  
 30 acetophenones,  $\alpha$ -aminoacetophenones, i-propylthioxanthone, camphorquinone, phenylpropanedione, 5,7-diiodo-3-butoxy-6-fluorone, (eta-6-cumene)(eta-5-cyclopentadienyl)iron hexafluorophosphate, (eta-6-cumene)(eta-5-cyclopentadienyl)iron tetrafluoroborate,  
 35 (eta-6-cumene)(eta-5-cyclopentadienyl)iron hexafluoroantimonate, substituted diaryliodonium salts, triarylsulfonium salts or a mixture of these compounds are employed.

As coinitiators for photochemical curing, tertiary amines, borates, organic phosphites, diaryliodonium compounds, thioxanthenes, xanthenes, fluorenes, fluorones,  $\alpha$ -dicarbonyl compounds, fused  
5 polyaromatics or a mixture of these compounds are preferably employed. Particularly preferably, N,N-dimethyl-p-toluidine, N,N-dialkylalkylanilines, N,N-dihydroxy-ethyl-p-toluidine, 2-ethylhexyl p-(dimethylamino)-benzoate, butyrylcholine  
10 triphenylbutylborate or a mixture of these compounds are employed.

As initiators, "thermal initiators" can also be employed which can bring about the curing of the  
15 material by the absorption of thermal energy at elevated temperature. In this context, preferably inorganic and/or organic peroxides, inorganic and/or organic hydroperoxides,  $\alpha,\alpha'$ -azobis(isobutyroethyl ester),  $\alpha,\alpha'$ -azobis(isobutyronitrile), benzopinacols or  
20 a mixture of these compounds are employed. Particularly preferably, diacyl peroxides such as, for example, benzoyl peroxide or lauroyl peroxide, cumene hydroperoxide, benzopinacol, 2,2'-dimethylbenzopinacol or a mixture of these compounds are employed.

25

For chemical curing at room temperature, inter alia, a redox initiator system is used which consists of one or more initiators and a coinitiator or coinitiators serving as an activator. For reasons of the storage  
30 stability, initiator or initiators and coinitiator or coinitiators are incorporated into parts of the dental material according to the invention which are spatially separate from one another, i.e. a multicomponent, preferably a two-component, material is present. As the  
35 initiator or initiators, preferably inorganic and/or organic peroxides, inorganic and/or organic hydroperoxides, barbituric acid derivatives, malonyl-sulfamides, protic acids, Lewis or Broensted acids or compounds which release such acids, carbenium ion

donors such as, for example, methyl triflate or triethyl perchlorate or a mixture of these compounds and, as a coinitiator or as coinitiators, preferably tertiary amines, heavy metal compounds, in particular  
5 compounds of the 8th and 9th group of the periodic table ("iron and copper group"), compounds having ionically bound halogens or pseudohalogens such as, for example, quaternary ammonium halides, weak Broensted acids such as, for example, alcohols and water or a  
10 mixture of these compounds are employed.

In the dental material according to the invention, any conceivable combination of the initiators and coinitiators described above can also be contained. An  
15 example of this is "dual-curing dental materials", which contain both photoinitiators and optionally the corresponding coinitiators for photochemical curing and initiators and corresponding coinitiators for chemical curing at room temperature.

20

For the adjustment of specific properties, the dental material according to the invention can additionally contain "additives" or "modifiers". Without restricting  
generality, some examples are mentioned below:  
25 inorganic and/or organic color pigments or dyes, stabilizers (such as, for example, substituted and unsubstituted hydroxyaromatics, tinuvin, terpinenes, phenothiazine, "HALS" - hindered amine light stabilizers - and/or heavy metal scavengers such as  
30 EDTA), plasticizers (such as, for example, polyethylene glycols, polypropylene glycols, unsaturated polyesters, phthalates, adipates, sebacates, phosphoric acid esters, phosphonic acid esters and/or citric acid esters), ion-emitting substances, in particular those  
35 which release fluoride ions (such as, for example, sodium fluoride, potassium fluoride, yttrium fluoride, ytterbium fluoride and/or quaternary ammonium fluorides), bactericidal or antibiotically active substances (such as, for example, chlorhexidine,

pyridinium salts, penicillins,  
tetracyclines, chloramphenicol, antibacterial  
macrolides and/or polypeptide antibiotics) and/or  
solvents (such as, for example, water, acetone,  
5 ethanol, i-propanol, butanone and/or ethyl acetate).

The dental material according to the invention can be  
used for prosthetic, preservative and preventive  
dentistry. Without claim to completeness, some use  
10 examples may be mentioned representatively:  
tooth filling materials, stump buildup materials,  
materials for temporary crowns and bridges, dental  
cements, adhesives, materials for artificial teeth,  
veneer materials, sealing materials and dental  
15 lacquers.

The invention is illustrated below with the aid of  
exemplary embodiments. First, various measurement and  
test procedures used are explained, subsequently the  
20 examples and comparative examples follow.

### I. Measurement and test procedures

#### **1. Particle size determination of the nanoscale 25 fillers**

The particle size determinations were carried out by  
means of dynamic light scattering (3D-PCS). The method  
allows the determination of the proportions by weight  
30 of particle sizes in the range from 1 nm up to a few  
micrometers. The upper limit of the method is afforded  
in that larger particles sediment in the measurement  
solution and thus cannot be determined.

35 All samples were investigated as dilute dispersions in  
2-butanone, a solids content of approximately 0.5% by  
weight being set. This dilution was chosen primarily in  
order to safely exclude particle-particle interactions.



## 2. Particle size mood of the microfillers

The particle size distribution is determined by means of laser diffractometry (type: Coulter LS 130). In this  
5 procedure, the proportion by weight of particles which have a certain size is determined. A characteristic is the  $d_{50}$  value, which indicates that half (50%) of the total mass of the particles exceed or fall below this size. The measurement of the particles is carried out  
10 in dilute, usually aqueous, dispersions.

## 3. Determination of the particle number content of the aggregates of the nanoscale fillers

15 The dispersion of filler and organic binder is investigated by means of an electron microscope. In the analysis, those particles are counted in which primary particles are bonded superficially to one another (aggregated).  
20

## 4. Polymerization shrinkage

The polymerization shrinkage was determined using the "buoyancy method". This method operates according to  
25 the principle of the hydrostatic balance on the basis of Archimedes principle: The buoyancy which a body experiences is equal to the weight of the amount of liquid displaced by it. Thus the buoyancy is equal to the weight loss which it experiences after immersion in  
30 a liquid.

In distilled water at 4°C, the buoyancy and thus the weight loss is directly equal to the volume of the body investigated.  
35

For the measurement of the polymerization shrinkage, i.e. the volume decrease, in the present cases the sample to be measured in each case was fixed to a very thin thread and connected firmly to the balance dish of

an electronic analytical balance (Sartorius A200 S). The dry weight  $m_{\text{air}}$  was measured. A water-filled beaker in which the sample was completely immersed was then additionally introduced into the balance. The mass of the sample  $m_1$  and also the water temperature and thus the density of the water  $\rho_1$  were determined. The sample was subsequently cured using an Espe Elipar II halogen lamp (three times 40 seconds) and stored dry for 24 hours at 23°C. The mass of the sample  $m_2$  (again completely immersed in water) and the water temperature and thus the density of the water  $\rho_2$  were determined. The polymerization shrinkage  $\Delta V$  was calculated according to the following formula:

$$\Delta V [\%] = 100 [\Delta m_1 - (\rho_1 / \rho_2) \Delta m_2] / \Delta m_1$$

In the equation:  $\Delta m_1 = m_{\text{air}} - m_1$  and  $\Delta m_2 = m_{\text{air}} - m_2$

## 5. Flexural strength

With the aid of a mold made of stainless steel, test bodies having the dimensions  $(40 \pm 2)$  mm x  $(2 \pm 0.1)$  mm x  $(2 \pm 0.1)$  mm were prepared (curing in a Dentacolor XS light oven: 90 seconds per side). The test bodies were stored in distilled water for 23 hours at 40°C and then stored for 1 hour at 23°C. Subsequently, the flexural strength was measured according to ISO 4049-2000 with the aid of a universal test machine from Zwick (type Z 010 / TN2A):

- constant advance rate: 0.8 mm / min
- calculation of the flexural strength (FS) according to the following formula:

$$FS \text{ [MPa]} = (3 F l) / (2 b h^2)$$

35

where  $F$  is the maximum force exerted on the test body, in Newtons;

$l$  is the distance between the supports with an accuracy of  $\pm 0.01$  mm,

in millimeters;

b is the breadth of the test body measured immediately before testing; in millimeters;

h is the height of the test body measured immediately before testing; in millimeters.

## 6. Compressive strength

With the aid of a mold made of stainless steel, cylindrical test bodies having a height of  $4 \pm 0.02$  mm and a diameter of  $2 \pm 0.01$  mm were prepared (curing using an Espe Elipar II halogen lamp: 40 seconds per side). The test bodies were stored in distilled water for 23 hours at 40°C and then stored for 1 hour at 23°C. Subsequently, the compressive strength was measured with the aid of a universal test machine from Zwick (type Z 010 / TN2A):

- constant advance rate: 1.0 mm / min

- calculation of the compressive strength (CS)

according to the following formula:

$$CS [MPa] = F / (\pi r^2)$$

where F is the maximum force exerted on the test body, in Newtons;

r is the radius of the test body; in millimeters.

## 7. Diametrical tensile strength

30

With the aid of a mold made of stainless steel, cylindrical test bodies having a height of  $3 \pm 0.01$  mm and a diameter of  $6 \pm 0.01$  mm were prepared (curing in a Dentacolor XS light oven: 90 seconds per side). The test bodies were stored in distilled water for 23 hours at 40°C and then stored for 1 hour at 23°C. Subsequently, the diametrical tensile strength was measured according to ADA specification No. 27 of 1977

with the aid of a universal test machine from Zwick (type Z 010 / TN2A):

- constant advance rate: 1.0 mm / min
- calculation of the diametrical tensile strength (DT)

5 according to the following formula:

$$DT [MPa] = 2 F / (\pi d h)$$

10 where... F is the maximum force exerted on the test body, in Newtons;

d is the diameter of the test body; in millimeters.

h is the height of the test body; in millimeters.

15

#### 8. Barcol hardness

With the aid of a mold made of stainless steel, 20 cylindrical test bodies having a height of  $2.5 \pm 0.1$  mm and a diameter of  $25 \pm 0.1$  mm were prepared (curing in a Dentacolor XS light oven: 180 seconds per side). Subsequently, the Barcol hardness was measured with the aid of a Barber-Colman impressor. Here, in each case at 25 least 5 values distributed on the test body were measured and the mean value was formed.

#### 9. Polymerization depth

30 The polymerization depth was determined according to ISO 4049-1988. Here, a hollow cylinder having a height of 10 mm and a diameter of 5 mm was selected as the test body mold. The respective sample was exposed for 20 seconds using a Kulzer Translux EC halogen lamp.

35

#### 10. Water absorption

The water absorption was determined according to ISO 4049-2000. Here, a hollow cylinder of aluminum having a

height of  $1.0 \pm 0.1$  mm and an internal diameter of  $15 \pm 0.1$  mm was selected as the test body mold. The respective sample was exposed for 180 seconds each side in a Dentacolor XS light oven.

5

### 11. Abrasion

The abrasion was determined using the method of 3-media abrasion developed in 1986 by DeGee (cf. A. J. DeGee et al., J. Dent. Res. 65 (5), 1986, pp. 654-658).

10

For the preparation of the test bodies, a mold adapted to the low spots of the sample wheel was used. The material was introduced into the mold in layers (about 15 2 mm per layer) and cured for 40 seconds in each case using an Espe Tri-Light halogen lamp. Immediately thereafter, the samples were additionally recured for 90 seconds in a Kuraray CS 110 light oven. The various material samples were stuck in random arrangement to 20 the sample wheel of the 3-media abrasion machine. To guarantee a uniform rounding and surface, the sample wheel was ground flat in the wet-grinding procedure (1000 grid). Immediately after preparation, storage was carried out for at least two weeks at 37°C in distilled 25 water.

All materials were loaded for four times 50,000 cycles in the 3-media abrasion machine according to the described procedure (Krämer 1997). The profilometric 30 measurement of the abrasion body was carried out by means of a computer-assisted perthometer C5D (Perthen, Göttingen). The 3-D data thus obtained were then analyzed with the aid of the image processing user interface XPERT for Windows. To this end, the abrasion 35 range was accurately defined and output from the abraded volume of the mean height loss underneath the drawn plane.

## II. Examples and comparative examples

Without restriction of the generality, the invention is illustrated in more detail below with the aid of a number of examples.

5

Nanofiller A:

First, 150 g of Aerosil OX 50 (Degussa AG) were added to a reactor vessel and 220 g of dichloromethane were sucked into the reactor vessel in vacuo and with stirring. Afterwards, a solution of 7.6 g of 3-methacryloxypropyltrimethoxysilane (ABCR GmbH & Co. KG), 3.3 g of distilled water and 12 mg of methacrylic acid in 580 g of dichloromethane was likewise sucked into the vessel. After completion of this operation, the solvent mixture was distilled off in vacuo and a white powder was obtained.

10  
15

Nanofiller B:

150 g of Aerosil 200 (Degussa AG) were weighed into a 2 l two-necked flask and treated with about 1000 g of 2-butanone. The initially pasty mass was stirred with a KPG stirrer until a homogeneous liquid suspension was formed. 95.55 g of 3-methacryloxypropyltrimethoxysilane were then added dropwise using a dropping funnel. The watery suspension was stirred for a total of 48 hours. Subsequently, the 2-butanone was slowly stripped off on a rotary evaporator. After the removal of the solvent, a white, fluffy, coarsely particulate porous powder remained, which easily decomposed.

20  
25  
30

Resin A:

1.97 g of camphorquinone, 3.21 g of 2-ethylhexyl 4-(dimethylamino)benzoate and 65.8 mg of 2,6-bis-tert-butyl-4-methylphenol were dissolved in 649.7 g of a 1:1 mixture of bisphenol A diglycidyl methacrylate and triethylene glycol dimethacrylate.

35

Volume shrinkage after 24 h: 10.7%

Nanofilled resin B-1 (precursor of reference example 2-1):

A total of 96.7 g of the nanofiller A were incorporated in portions into 100 g of resin A in the course of 2  
5 hours with the aid of a Dispermat. In this manner, a slightly opaque, medium-viscosity, filled resin having a degree of filling of 49.2% of nanoscale silicon dioxide was obtained. The particle size distribution of the nanofilled resin B-1 ought to be measured with the  
10 aid of dynamic light scattering. The problem occurred here, however, that very large aggregates and/or agglomerates (having a mean particle size  $d_{50} > 1 \mu\text{m}$ ) were present in the resin, which separated before or during measurement and thus were unable to be  
15 additionally measured. Therefore in figure 1 the particle size distribution only of the particles of nanofilled resin B-1 which were able to be measured is depicted.

20 Transparency: 56.2%  
Volume shrinkage after 24 h: 5.2%

Figure 1 shows the particle size distribution of the unseparated particles of the nanofilled resin B-1  
25 (dynamic light scattering)

Peak 1:

Mean value = 75.8 nm; breadth = 12.5%; amplitude = 34.5%

30 Peak 2:

Mean value = 212.7 nm; breadth = 11.1%; amplitude = 65.5%

Taking into consideration the relatively high proportion of unmeasurable aggregated and/or agglomerated particles having a particle size  $d > 1 \mu\text{m}$ , it can be concluded from the above figure that only a very small proportion of the particles of the nanofilled resin B-1 has a particle size  $d < 100 \text{ nm}$ .

10 Nanofilled resin B-2 (precursor of reference example 2-2):

A total of 96.7 g of the nanofiller A were incorporated in portions into 100 g of the resin A within one hour with the aid of a laboratory mixer. In this manner, a slightly opaque, medium-viscosity, filled resin having a degree of filling of 49.2% of nanoscale silicon dioxide was obtained.

In the case of this resin, it was not possible to measure the particle size distribution with the aid of dynamic light scattering, since at least 80% of the filler was so strongly aggregated and/or agglomerated that the corresponding particles were so large that they separated and were thus unable to be measured.

Transparency: 56.4%

25 Volume shrinkage after 24 h: 5.3%

Nanofilled resin C (precursor of inventive examples):

Approximately 50 g of the nanofiller B were added to 250 g of a 1:1 mixture of bisphenol A diglycidyl methacrylate and triethylene glycol dimethacrylate and incorporated in 90 minutes at 1200 rpm with the aid of a Dispermat. A further 40 g of the nanofiller B were then added, and the mixture was dispersed for 1 hour at 1000 rpm and subsequently overnight at 500 rpm. A total of 225 g of the nanofiller were dispersed in portions of 30 - 40 g. Subsequently, 0.16% by weight of camphorquinone, 0.26% by weight of 2-ethylhexyl 4-(dimethylamino)benzoate and 0.005% by weight of 2,6-bis-tert-



butyl-4-methylphenol were dissolved in this homogeneous mixture. In this manner, a very transparent, medium-viscosity, filled resin having a degree of filling of 47.2% of nanoscale silicon dioxide was obtained.

In contrast to the nanofilled resins B-1 and B-2, no separation occurred in the case of this resin, so that in this case it was possible to determine the particle size distribution of all particles by means of dynamic light scattering (see figure 2).

Transparency: 94.5%

Volume shrinkage after 24 h: 7.3%

Figure 2 shows a particle size distribution of nanofilled resin C (dynamic light scattering)

Peak 1:

Mean value = 35.2 nm; breadth = 31.9%; amplitude = 77.2%

Peak 2:

Mean value = 159.1 nm; breadth = 17.5%; amplitude = 22.8%

The above figure clearly proves that more than 50% of the particles of the nanofilled resin C have a particle size  $d < 100$  nm.

In the following examples 1 - 4, hybrid composites are presented which were prepared according to the prior art (reference examples) or according to the present invention. It is to be noted that all 5 pastes were adjusted sensorially to the same consistency.

Example 1 (reference):

6.0 g of Aerosil R 974 (Degussa AG) and 130.7 g of silanized barium silicate glass having a mean particle size of 1.0  $\mu\text{m}$  were incorporated into 34.1 g of resin A. Subsequently, the mixture was degassed at about

200 mbar for about 60 minutes. In this manner, a solid, modelable, light-curing paste was obtained.

Composition: see Table 1

5 Properties: see Table 2

Example 2-1 (reference):

70.6 g of silanized barium silicate glass having a mean particle size of 1.0  $\mu\text{m}$  were initially incorporated  
10 into 50.0 g of the nanofilled resin B-1. The resulting paste, however, was so solid and crumbly that it was additionally diluted with 10.0 g of resin A. Subsequently, the paste was degassed at about 200 mbar for about 60 minutes. In this manner, a solid,  
15 modelable, light-curing paste was obtained.

Composition: see Table 1

Properties: see Table 2

20 Example 2-2 (reference):

60.8 g of silanized barium silicate glass having a mean particle size of 1.0  $\mu\text{m}$  were initially incorporated  
into 50.0 g of the nanofilled resin B-2. The resulting paste, however, was slightly too solid and was  
25 therefore additionally diluted with 1.0 g of resin A. Subsequently, the paste was degassed at about 200 mbar for about 60 minutes. In this manner, a solid, modelable, light-curing paste was obtained.

30 Composition: see Table 1

Properties: see Table 2

Example 3 (invention):

105.5 g of silanized barium silicate glass having a mean particle size of 1.0  $\mu\text{m}$  were incorporated into  
35 50.1 g of the nanofilled resin C. Subsequently, the paste was degassed at about 300 mbar for about

60 minutes. In this manner, a solid, modelable, light-curing paste was obtained.

Composition: see Table 1

5 Properties: see Table 2

Example 4 (invention):

10 6.0 g of Aerosil R 974 (Degussa AG) and 95.6 g of silanized barium silicate glass having a mean particle size of 1.0  $\mu\text{m}$  were incorporated into 54.1 g of the filled resin C. Subsequently, the paste was degassed at about 200 mbar for about 60 minutes. In this manner, a solid, modelable, light-curing paste was obtained.

15

Composition: see Table 1

Properties: see Table 2

20 Table 1: Percentage composition of the hybrid composites (Exs. 1 - 4)

	Ex. 1 (reference)	Ex. 2-1 (reference)	Ex. 2-2 (reference)	Ex. 3 (invention)	Ex. 4 (invention)
Resin A	20.0%	7.65%	0.9%	—	—
Nanofilled resin B-1	—	38.3%	—	—	—
Nanofilled resin B-2	—	—	44.7%	—	—
Nanofilled resin C	—	—	—	32.2%	34.7%
Aerosil R 974	3.5%	—	—	—	3.9%
Barium silicate glass ( $d_{50}$ = 1.0 $\mu\text{m}$ )	76.5%	54.05%	54.4%	67.8%	61.4%

	Ex. 1 (reference)	Ex. 2-1 (reference)	Ex. 2-2 (reference)	Ex. 3 (invention)	Ex. 4 (invention)
Resin A	20.0%	27.1%	23.6%	17.0%	18.3%
Nanofiller A	—	18.8%	22.0%	—	—
Nanofiller B	—	—	—	15.2%	16.4%
Aerosil R 974	3.5%	—	—	—	3.9%
Barium silicate glass ( $d_{50}$ = 1.0 $\mu\text{m}$ )	76.5%	54.1%	54.4%	67.8%	61.4%

Table 2: Physical and mechanical properties of the hybrid composites (Exs. 1 - 4)

5

	Ex. 1 (reference)	Ex. 2-1 (reference)	Ex. 2-2 (reference)	Ex. 3 (invention)	Ex. 4 (invention)
Compressive strength [MPa]	409	431	459	513	493
Volume shrinkage after 24 h [%]	3.8	4.0	4.4	3.3	3.4
Abrasion [ $\mu\text{m}$ ]	41	n.d.	n.d.	n.d.	20
Flexural strength [MPa]	126	131	121	129	125
Diametrical tensile strength	53	59	58	57	57

[MPa]					
Barcol hardness	82	82	80	85	79
Polymer-ization depth [mm]	$\geq 10$	$\geq 10$	$\geq 10$	$\geq 10$	$\geq 10$
Water absorption [ $\mu\text{g}/\text{mm}^3$ ]	29	22	22	20	22

In the following examples 5 and 6, microfiller composites are presented which were prepared according to the prior art (reference example) or according to the present invention. It is to be noted that the two pastes were adjusted sensorially to the same consistency.

Example 5 (reference):

14.0 g of Aerosil R 974 (Degussa AG) and 86.1 g of a ground chip polymer which contained dodecanediol dimethacrylate, trimethylolpropane trimethacrylate and silanized Aerosil OX 50 were incorporated into 40.0 g of resin A. Subsequently, the paste was degassed at about 300 mbar for about 45 minutes. In this manner, a solid, modelable, light-curing paste was obtained.

Composition: see Table 3

Properties: see Table 4

Example 6 (invention):

100.7 g of the ground chip polymer described in ex. 5 were incorporated into 54.0 g of the nanofilled resin C. Since the resulting paste was too solid, it was diluted with 12.4 g of the nanofilled resin C. Subsequently, the paste was degassed at about 200 mbar

for about 60 minutes. In this manner, a solid, modelable, light-curing paste was obtained.

Composition: see Table 3

5 Properties: see Table 4

Table 3: Percentage composition of the micro-  
filler composites (Exs. 5 - 6)

	Ex. 5 (reference)	Ex. 6 (invention)
Resin A	28.6%	—
Nanofilled resin C	—	39.7%
Aerosil R 974	10.0%	—
Org. filler (ground prepolymer)	61.4%	60.3%

10

	Ex. 5 (reference)	Ex. 6 (invention)
Resin A	28.6%	21.0%
Nanofiller B	—	18.7%
Aerosil R 974	10.0%	—
Org. filler (ground prepolymer)	61.4%	60.3%

Table 4: Physical and mechanical properties of  
the microfiller composites (Exs. 5 - 6)

15

	Ex. 5 (reference)	Ex. 6 (invention)
Compressive strength [MPa]	249	345

Volume shrinkage after 24 h [%]	3.6	3.0
Abrasion [ $\mu\text{m}$ ]	64	42
Diametrical tensile strength [MPa]	36	36
Barcol hardness	59	62
Polymerization depth [mm]	$\geq 10$	$\geq 10$
Water absorption [ $\mu\text{g}/\text{mm}^3$ ]	23	20

These results show that the use of the composition employed according to the invention in dental materials leads to an increase in the compressive strength, to a  
5 lowering of the polymerization shrinkage and to an improvement of the abrasion resistance.